

ELECTRONIC FUNDAMENTALS

EXPERIMENT LESSON 22

ELECTRON TUBE EXPERIMENTS



RCA INSTITUTES, INC.

**A SERVICE OF RADIO CORPORATION OF AMERICA
HOME STUDY SCHOOL**

350 West 4th Street, New York 14, N. Y.

Experiment Lesson 22

OBJECT

To study the significance of the important electron-tube characteristics, and how they can be measured.

INFORMATION

In Theory Lesson 22 you learned about important electron-tube characteristics such as amplification factor, transconductance, and plate resistance. In that lesson you also learned how these could be found using the tube characteristic curves that are given in the tube manual. Now you will see how these tube characteristics can be found by direct measurement. Although these characteristics are used mainly by design engineers, good servicemen understand their meaning and know how they affect the operation of the circuit in which the tube is used.

In this lesson, you will measure the amplification factor, transconductance, and plate resistance of the 6AT6 tube, which is used as a voltage amplifier in your radio receiver. If you perform your experiments carefully and make accurate measurements, you will find that your results will agree closely with those given in the tube manual.

EQUIPMENT NEEDED

Radio-receiver chassis with wired, operating power supply

Multimeter

Signal generator

One 47,000-ohm 1-watt resistor

One 22,000-ohm 2-watt resistor

One 10,000-ohm 1/2-watt resistor
(remove from resistor board)

One 1,000-ohm 2-watt resistor

Pointer knob (from signal generator)

One 6AT6 tube

Four flashlight cells

One 3-lug terminal strip

One 7-pin miniature socket, and mounting hardware.

Phone tip - alligator clip meter lead (from Exp 2)

One 3 x 5 white card

JOB 22-1

To mount the 7-pin miniature socket for the 6AT6 tube, wire the filament circuit, and prepare the circuit for the following experiments. The setup for this job is shown in Fig. 22-1.

Procedure

Step 1. Install the 6AT6 socket in its hole. Make sure that the space between pins 1 and 7 of the socket is facing the front of the chassis as shown in Fig. 22-1. Fasten the socket with 4-40 x 1/4-inch screws, No. 4 lockwashers, and hex nuts.

Step 2. Mount a three-lug terminal strip as shown in the figure.

Note: Now that the signal generator is completed, all terminal strip designations refer to the radio-receiver chassis. The

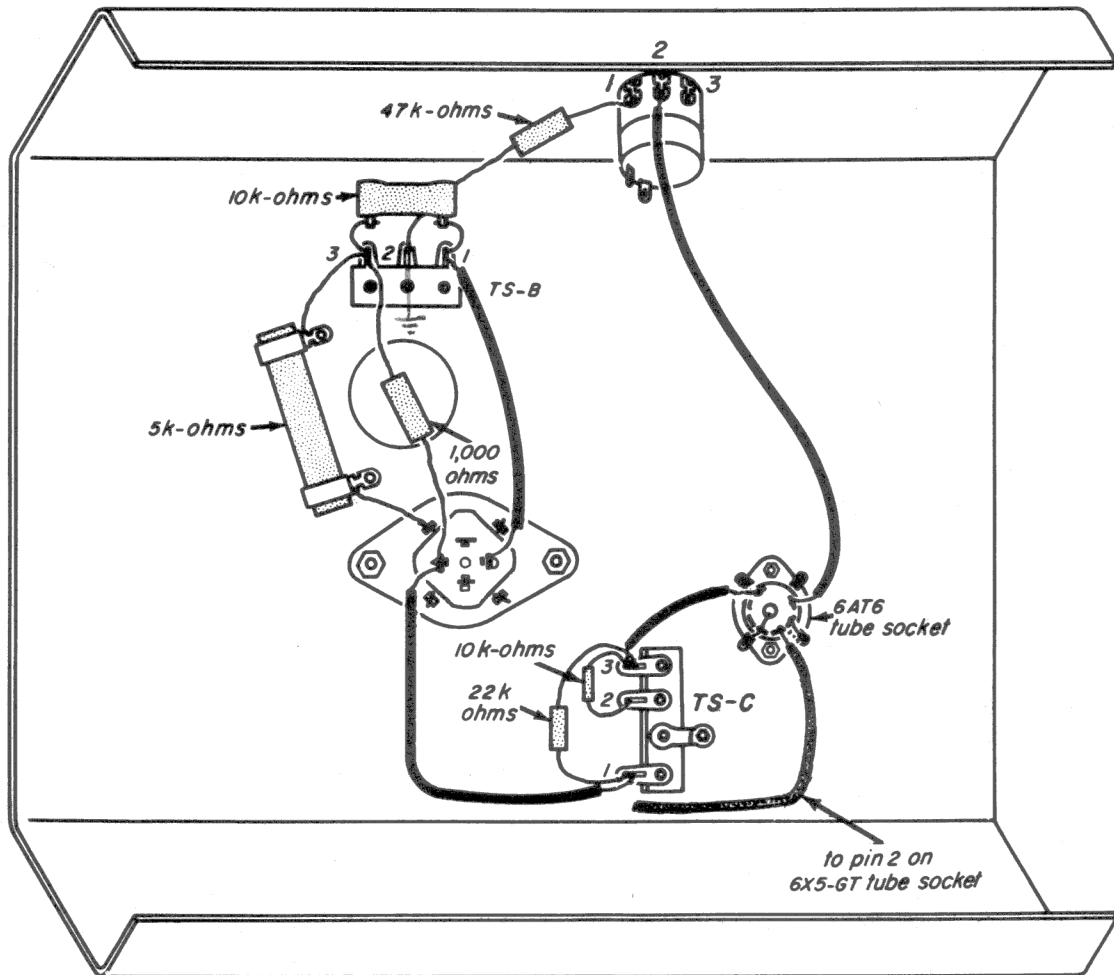


Fig. 22-1

terminal strip to which the a-c line cord is connected will now be called TS-A; the three-lug terminal strip to which 5 k-ohm and 10 k-ohm bleeder resistors are connected will be called TS-B; and the three-lug terminal strip that you installed in Step 2 will be called TS-C. Label these on your chassis with a crayon.

Step 3. With a piece of hookup wire, connect pin 2 of the 6X5 socket to pin 3 of the 6AT6 socket. Dress this lead as shown in the figure and keep it down close to the chassis. This is a permanent connection.

Step 4. With a piece of bare wire, connect together pin 4, the center post, and the grounding lug next to pin 4, all on the 6AT6 socket, as shown in the figure.

Note: All other solder connections that follow are to be made as temporary connections.

Step 5. Connect pin 2 of the 6AT6 socket to the grounding lug next to it, as in the figure.

Step 6. Connect a lead from pin 7 of the 6AT6 tube socket to lug 3 of TS-C.

Step 7. Interchange the positions of the 5 k-ohm and 10 k-ohm bleeder resistors so that the 10-k-ohm resistor is connected across TS-B, and the 5 k-ohm resistor is connected from lug 3 to chassis, as shown in Fig. 22-1.

Step 8. Connect a 1,000-ohm 2-watt resistor from lug 3 of TS-B to the 20- μ f terminal of the electrolytic capacitor (marked with a triangle Δ) as shown in the figure. A schematic diagram of the power supply portion of the receiver as you now should

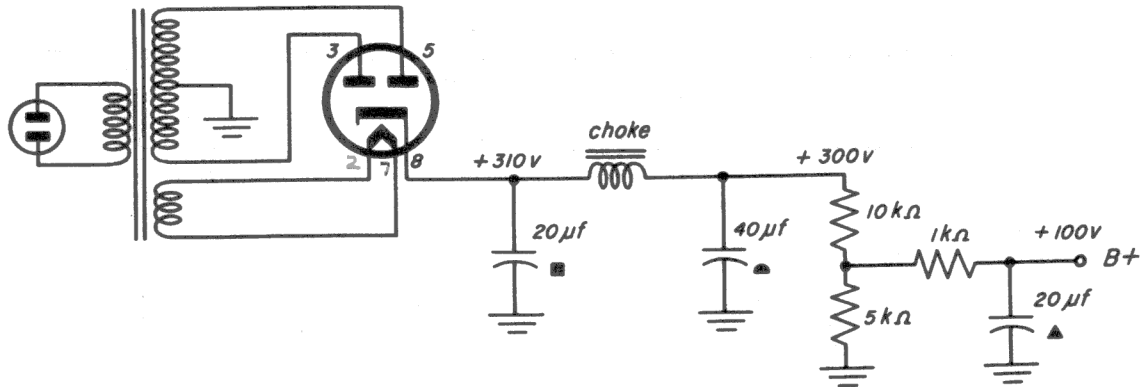


Fig. 22-2

have it wired is shown in Fig. 22-2. The approximate no-load voltages are also shown.

Step 9. Connect the 22,000-ohm 2-watt resistor across lugs 1 and 3 of TS-C.

Step 10. Connect a 10,000-ohm resistor across lugs 2 and 3 of TS-C.

Step 11. Connect a lead from lug 1 of TS-C to the 20- μ f terminal (marked with a triangle Δ) of the electrolytic capacitor. At this point, the new wiring on your receiver chassis should appear similar to that shown in Fig. 22-1, except for the 47 k-ohm resistor and the wire from pin 1 of the 6AT6.

JOB 22-2

To prepare an adjustable, accurately calibrated bias voltage supply.

Information. In a previous experiment, you made an adjustable bias supply by connecting a 6-volt battery across a potentiometer, as shown in Fig. 22-3. The potentiometer is used as a variable voltage divider. A voltage continuously variable between zero and 6 volts is then available between the center terminal of the potentiometer and its bottom terminal. If the potentiometer is calibrated, the amount of bias output at any position of the potentiometer can be found without having to measure bias with the multimeter. This makes it more convenient to perform your experiments, because you will not have to switch the meter back and forth from the grid to the plate circuits of the tube and you will not have to change the meter setting so often. If the potenti-

ometer resistance is high, the drain on the batteries is very low. Therefore, the voltage of the battery will remain constant, and the calibration will remain accurate for a long period of time.

In the previous experiment, the calibration was done by measuring the voltage output with the multimeter at various positions of the potentiometer. However, the meter resistance loads the circuit enough to introduce errors. The sensitivity of your meter is very high, but even a 20,000-ohms per volt meter loads the circuit enough to make the calibration inaccurate, due to the high resistance of the potentiometer. Thus, if the potentiometer is adjusted until the meter reads -1.5 volts, the voltage will not be -1.5 volts at that setting when the meter is removed. Although this error was not large enough to interfere with the experiments on principles of triode tubes, it makes it impossible to obtain accurate results in the measurement of tube characteristics.

The error due to meter loading can be avoided by calibrating the potentiometer using resistance measurements. This requires doing a little calculation, but you will then have a bias-voltage supply that is quite accurately calibrated.

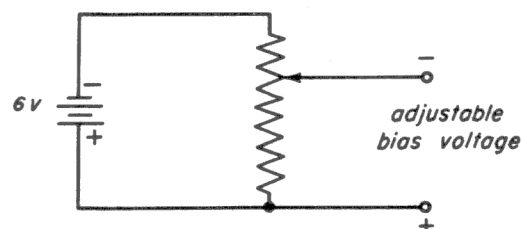


Fig. 22-3

Suppose we have a battery of E volts connected across a potentiometer whose total resistance is R ohms, as shown in Fig. 22-4. Let's call the resistance between the moving terminal and the bottom terminal r ohms, as in the figure. From the principles of voltage-divider action that you studied, the voltage output e can be found by using the following formula:

$$e = \frac{r}{R} E$$

Solving for r in this formula gives:

$$r = \frac{R}{E} e$$

The quantity R/E is the ohms-per-volt figure of the voltage divider and gives the resistance r needed for each volt output from the potentiometer. To use the formula, measure the total resistance of *your* potentiometer very carefully, using the $R \times 10K$ -ohm scale of the multimeter. (Make sure the multimeter has been carefully zeroed before making the measurement.) Read the meter as accurately as you can. Then measure the voltage output of your battery of four series-connected flashlight cells, using the 25 VDC scale of the multimeter. Read the meter as accurately as you can. Now divide the resistance you measured by the voltage you measured. This gives the ohms-per-volt figure of the voltage-divider circuit. For instance, suppose the resistance is exactly 500,000 ohms, and the voltage is exactly 6 volts. Dividing gives 83,300 ohms-per-volt (the division need be carried out accurately only to three places.) Since this resistance is to be measured on the $R \times 10K$ scale of the meter, it is rearranged like this: $8.33 \times 10K$. If we connect the ohmmeter across the bottom and moving terminal of the potentiometer and adjust it to read $8.33 \times 10 K$ -ohms, the point to which the potentiometer is set can be marked - 1.0 volt.

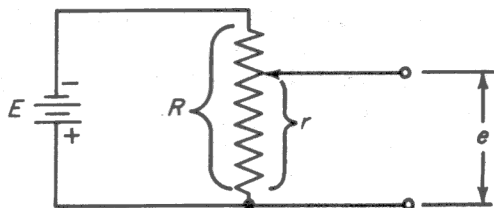


Fig. 22-4

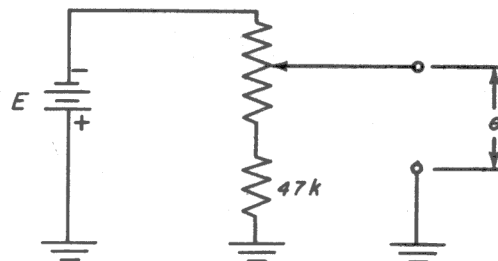


Fig. 22-5

To calibrate the potentiometer over the required range, we prepare a table like this:

Calibration				Ohmmeter Reading			
8.33	x	10K	x	1.0	=	8.33	x 10K
8.33	x	10K	x	1.1	=	9.15	x 10K
8.33	x	10K	x	1.2	=	10.0	x 10K
8.33	x	10K	x	1.3	=	10.8	x 10K
8.33	x	10K	x	1.4	=	11.66	x 10K
8.33	x	10K	x	1.5	=	12.5	x 10K
8.33	x	10K	x	1.6	=	13.3	x 10K
8.33	x	10K	x	1.8	=	15.0	x 10K
8.33	x	10K	x	2.0	=	16.67	x 10K
8.33	x	10K	x	2.5	=	20.8	x 10K
8.33	x	10K	x	3.0	=	25	x 10K

By adjusting the potentiometer carefully until the meter indicates each one of these resistance values, the corresponding voltage value can be marked at the potentiometer setting. The resulting calibration will be much more accurate than the one obtained by measurement with the meter.

If you will look at the calibration card previously made by meter measurement, you will also notice that the region between 0 and 0.5 volt is very expanded, while the rest of the card is crowded. This is because the potentiometer is nonlinear, as required for its ultimate use as a volume or tone control. We can take advantage of the expanded portion of the scale by putting a 47,000-ohm resistor in series with the chassis side of the potentiometer, as shown in Fig. 22-5. This changes the voltage distribution so that the interval between - 1.0 volt and - 2.0 volts is spread out over the expanded scale. The calibrated card will then look something like Fig. 22-6.

Procedure.

Step 1. Connect a 47 k-ohm resistor from terminal 1 of the potentiometer to lug 2 (chassis) of TS-B, as shown in Fig. 22-1.

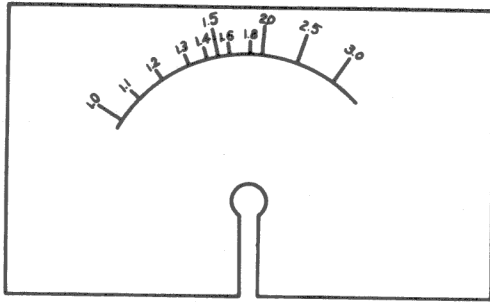


Fig. 22-6

Step 2. Connect a lead from terminal 2 of the potentiometer to pin 1 (grid) of the 6AT6 tube socket.

Step 3. Mount a new white card over the control shaft, as described in Job 19-4 of Lesson 19.

Step 4. Cut a piece of bare wire 2-3/4 inches long, and shape it exactly as shown in Fig. 22-7a. Place the hook in the wire over the control shaft, and hold it in place by putting the pointer knob on the shaft over the wire and tightening the set screw of the knob, as shown in Fig. 22-7b. Adjust the wire so that the point is about 1/16 inch away from the surface of the card, so that it does not scrape the card as the knob is turned.

Step 5. Set up your multimeter to the 25 VDC scale, and measure the output voltage of your 4-cell battery. Read the meter as carefully as you can.

Step 6. Set up your multimeter to measure resistance on the R X 10K scale. Carefully zero the meter, and measure the resistance from terminal 3 of the potentiometer to chassis.

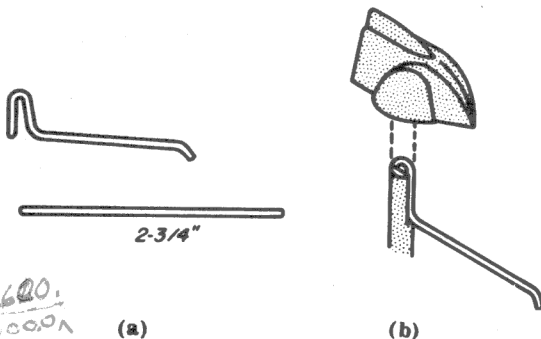


Fig. 22-7

Note: The six volt battery is not connected into the circuit. Read the meter as carefully as you can.

Step 7. Divide the resistance reading by the voltage reading to obtain the ohms-per-volt figure for the circuit.

Step 8. Fill out the table below, multiplying your ohms-per-volt figure by the voltage given in each line of the table:

VOLTAGE (volts)	RESISTANCE (ohms)
1.0 v.	<u>9.26</u> x 10K
1.1 v.	<u>10.2</u> x 10K
1.2 v.	<u>11.1</u> x 10K
1.3 v.	<u>12.0</u> x 10K
1.4 v.	<u>13.0</u> x 10K
1.5 v.	<u>13.9</u> x 10K
1.6 v.	<u>14.8</u> x 10K
1.8 v.	<u>16.7</u> x 10K
2.0 v.	<u>18.5</u> x 10K
2.5 v.	<u>23.2</u> x 10K
3.0 v.	<u>27.8</u> x 10K

Step 9. Carefully zero the meter again on the R x 10K scale. Connect one lead of the meter to the center terminal of the potentiometer and the other lead of the meter to chassis. Use your clip lead with phone tips (made in Experiment Lesson 2) so that you can have your hands free. Make sure that the braided lead is well taped before you use it.

Step 10. Adjust the potentiometer carefully until the meter indicates the resistance value in the first line of the table, and mark the position of the pointer on the card. Label this point -1.0 volt.

Note: Always move the pointer in a clockwise direction to avoid errors that may be introduced by backlash in the potentiometer. If you pass over the correct spot for any setting, do not go back to it by turning the pointer back to that spot. Instead, turn the pointer all the way to the starting point, and then turn the pointer clockwise up to the desired point.

Step 11. Continue as in Step 10 until all the voltages in the table are marked on the

6.1V
56.5 x 10K
92600
150000
549
180
122
380
366
140

card. Your card should then appear similar to the one shown in Fig. 22-6.

JOB 22-3

To become familiar with the 6AT6 characteristics as given in the manual.

Procedure.

Step 1. Look up the 6AT6 tube in the tube manual, and fill out the following:

Type of tube: TWIN DIODE - HIGH MU TRIODE

Type of base: SMALL BUTTON 7 PIN MINIATURE

Heater 6.3 volts; 300 ma

Directly or indirectly heated cathode: INDIRECTLY

Maximum plate voltage: 300 volts

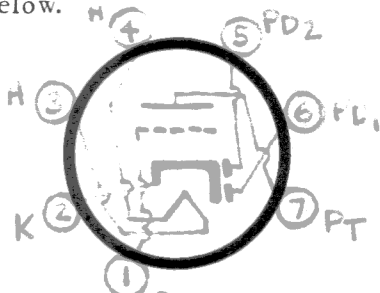
Maximum plate dissipation: .5 watts

Amplification factor: * 70

Mutual conductance: * 1300 μ mhos

Plate resistance: * 54,000 ohms

Draw a basing diagram of the tube, using the circle below.



EXPERIMENT 22-1 3T

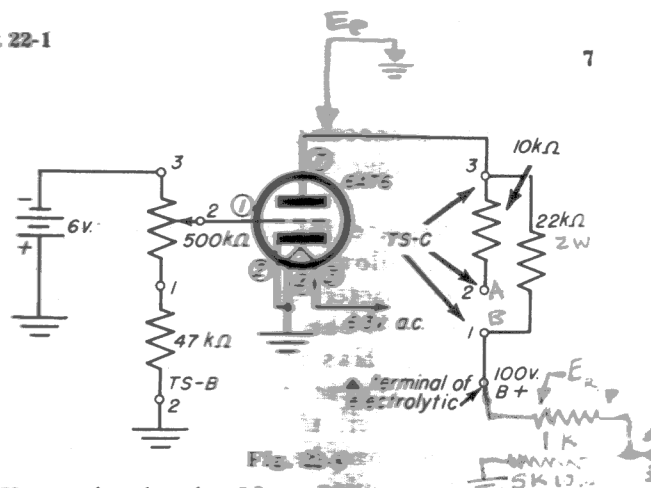
To measure the amplification factor of the 6AT6 triode tube.

Procedure

Step 1. Insert the 6AT6 tube in its socket.

Step 2. Connect the negative terminal of the 6-volt battery to terminal 3 of the potentiometer, and the positive terminal to any convenient point on the chassis.

*Based on plate voltage of 100 volts



Your circuit should not appear as in Fig. 22-8. Check it before you proceed.

Step 3. Connect the a-c line cord of the receiver to an a-c outlet, and allow the tubes to warm up.

Step 4. Set the calibrated potentiometer to exactly -1.0 volt.

Step 5. Set up the meter to the 100 VDC range, and measure the plate voltage across plate and cathode of the tube. (Touch positive meter test prod to pin No. 7 of the tube socket, and the negative meter test prod to the chassis.) Record your reading here:

15

Step 6. Measure the plate current of the tube. This is done by measuring the voltage drop across the 1,000-ohm resistor. For a 1,000-ohm resistor, the current flowing through it in milliamperes is numerically equal to the voltage drop across it in volts. Set the meter range switch on the 5 VDC position, and connect it across the 1,000-ohm resistor. (Touch the positive meter test prod to terminal 3 of TS-B and the negative meter test prod to the 22k-ohm terminal, marked with a Δ , of the electrolytic.) Record the current here:

.6

Step 7. Disconnect the a-c line cord. Short the 10 k-ohm resistor across the 22 k-ohm resistor to change the plate voltage.

Do this by connecting lugs 1 and 2 of TS-C together with your clip lead.

Step 8. Replace the a-c line cord in the socket, and allow the tubes to warm up. Connect the meter on the 5 VDC range across the 1,000-ohm resistor as in Step 6, and adjust the bias potentiometer until you get the same current through the resistor as before. Remember, if you pass the correct point, not to come back to it in a counter-clockwise direction, but start over again and move the pointer only in a clockwise direction. From the calibrated card, carefully read and record the bias voltage here:

1.16
volts

Step 9. Set the meter range switch to the 100 VDC position, and measure the plate to cathode voltage. Record it here:

90.8
volts

90.8
79.0
11.8

Step 10. Disconnect the a-c line cord.

Step 1. Compute the amplification factor:

$$\frac{\text{Change in plate voltage}}{\text{Change in grid voltage}} = \frac{11.8}{1.16} = 73$$

How do your results compare with the value given for the 6AT6 tube in the tube manual?

Discussion. The amplification factor of a tube is defined as the change in plate voltage divided by the change in grid voltage, with constant plate current. Typical results as obtained in our laboratory are as follows:

Change in plate voltage = 90 volts - 76 volts = 14 volts

Change in grid voltage = 1.2 volts - 1.0 volts = 0.2 volts

$$\mu = \frac{14 \text{ volts}}{0.2 \text{ volts}} = 70$$

In this experiment, the amplification factor of the tube is measured by producing a small change in plate voltage and then determining the grid-voltage change that is necessary to restore the original current. In our laboratory, with a 22 k-ohm resistor in series with the plate of the tube, and the bias set at -1.0 volt, 76 volts was measured at the plate. The voltage drop across the 1,000-ohm resistor was 0.7 volts, corresponding to a current of 0.7 ma. When the 10 k-ohm resistor was shunted across the 22 k-ohm resistor, the current increased. It was necessary to increase the bias to -1.2 volts to bring the current back down to 0.7 ma. The plate voltage across the tube was then found to be 90 volts. In this case, a 14-volt change on the plate was counteracted by a 0.2 volt change on the grid. Stated another way, a 0.2 volt change in the grid circuit has the same effect as a 14 volt change in the plate circuit. Thus, the grid voltage of this tube is 70 times more effective than the plate voltage in controlling the plate current.

EXPERIMENT 22-2

To measure the transconductance of a triode tube

Procedure

Step 1. Connect the a-c line cord to an a-c power outlet, and allow the tubes to warm up.

Step 2. Set the bias at -1.0 volt. (Remember to first reduce the bias below one volt, and then move the pointer in a clockwise direction to the one-volt point.)

Step 3. Set the meter range switch to the 100 VDC position, and measure the plate voltage (pin 7 and chassis). Make sure that the 10 k-ohm shunt is still connected by means of the clip lead from lugs 1 and 2 of TS-C. Record your reading here:

88.5
volts

Step 4. Set the meter range switch to the 5 VDC position. Determine the current

through the tube by measuring the voltage drop across the 1,000-ohm resistor. Record the result here:

8
ma

Step 5. Remove the shunt by disconnecting the clip lead.

Step 6. Increase the bias to exactly -1.5 volts.

Step 7. Measure the current through the tube. Record the result here:

.28
ma

Step 8. Set the meter range switch to the 100 VDC position, and measure the plate voltage. Record your reading here:

89
volts

Step 9. Disconnect the a-c line cord.

Step 10. Compute the transconductance:

$$G_m = \frac{\text{change in plate current}}{\text{change in grid voltage}} = \frac{.52 \text{ amps}}{.5} = .00104$$

$$= .00104 \text{ mhos} = 1040 \mu \text{ mhos}$$

How does your value compare with the one given in the tube manual.

Discussion. The transconductance of a tube is defined as

$$G_m = \frac{\text{change in plate current}}{\text{change in grid voltage}}$$

with constant plate voltage. In our laboratory setup to measure the transconductance of the 6AT6 tube, the following typical results were obtained:

$$\begin{aligned} \text{Change in plate current} &= 0.9 \text{ ma} - 0.3 \\ &\text{ma} = 0.6 \text{ ma} \end{aligned}$$

$$\begin{aligned} \text{Change in grid voltage} &= 1.5 \text{ v} - 1.0 \text{ v} \\ &= 0.5 \text{ v} \end{aligned}$$

$$\begin{aligned} G_m &= \frac{0.6 \text{ ma}}{0.5 \text{ v}} = \frac{0.0006 \text{ a}}{0.5 \text{ v}} = 0.0012 \text{ mhos} \\ &= 1,200 \mu \text{ mhos} \end{aligned}$$

This agrees closely with the value of transconductance given in the tube manual for the 6AT6 tube.

In this experiment, the bias was set at -1.0 volt as a starting point. With the 10 k-ohm shunt resistor connected, our measurements showed that the plate current was 0.9 ma, and the plate voltage was 87 volts. When the bias is increased, the plate current is reduced, and this raises the plate voltage. But the definition of transconductance calls for a constant plate voltage. This is done by removing the shunt, which, in our measurements, reduced the plate voltage back to 87 volts. The purpose of the shunt in this case is to keep the plate voltage constant, as called for in the definition of transconductance. The current at the increased bias was 0.3 ma. Thus, a change of 0.5 volts on the grid produced a change of 0.6 ma in the plate current. This corresponds to a transconductance of 1,200 micromhos.

The transconductance of a tube varies considerably, depending upon the average plate current at which the measurement is made. Our value of 1,200 micromhos is at an average plate current of about 0.6 ma. As the average plate current is increased, the transconductance is generally higher, as shown in Fig. 22-9. The amplification factor of a tube, however, remains fairly constant for different plate currents, as shown in this figure.

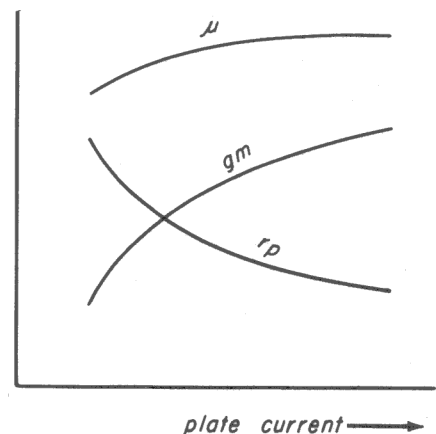


Fig. 22-9

EXPERIMENT 22-3

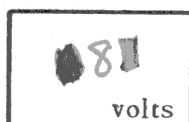
To measure the plate resistance of the 6AT6 triode tube.

Procedure.

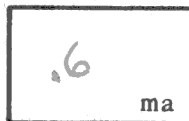
Step 1. Connect the line cord to an a-c outlet, and allow the tubes to warm up.

Step 2. Set the bias at exactly -1.0 volt.

Step 3. Set the meter range switch on the 100 VDC position, and measure the plate voltage. Record your reading here:

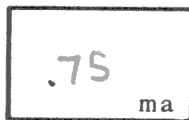


Step 4. Set the meter range switch on the 5 VDC position, and measure voltage drop across the 1,000-ohm resistor. Record your reading here:

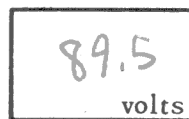


Step 5. Connect the 10 k-ohm shunt into the circuit by connecting the clip lead across lugs 1 and 2 of TS-C.

Step 6. Measure the current through the tube as in Step 4. Record your reading here:



Step 7. Set the meter range switch to the 100 VDC position and measure the plate voltage. Record your reading here:



Step 8. Disconnect the line cord, and return the pointer knob to the signal generator.

Step 9. Calculate the plate resistance:

$$r_p = \frac{\text{Change in plate voltage}}{\text{Change in plate current}} = \frac{8.5}{.15 \text{ ma}}$$

$$= 56,000$$

Discussion. The plate resistance of a tube is defined as:

$$\frac{\text{Change in plate voltage}}{\text{Change in plate current}}$$

with constant grid voltage. In our laboratory setup to measure the plate resistance of the 6AT6 tube, the following typical results were obtained with the bias held constant at -1.0 volt.

$$\text{Change in plate voltage} = 87 \text{ v} - 76 \text{ v} = 11 \text{ v}$$

$$\text{Change in plate current} = 0.9 - 0.7 \text{ ma} = 0.2 \text{ ma}$$

$$r_p = \frac{11 \text{ v}}{0.2 \text{ ma}} = \frac{11 \text{ v}}{0.0002 \text{ amps}} = 55,000 \text{ ohms.}$$

This agrees closely with the value of plate resistance given in the tube manual for the 6AT6 tube.

The voltage output of an amplifier stage divides between the plate resistance of the tube and the external load resistance of the amplifier circuit. Thus, it is important to know the plate resistance of a tube when choosing the size of the load resistor for maximum power output, or maximum undistorted power output, as explained in later lessons.

In this experiment, the bias was set at -1.0 volt, and held constant at this value throughout the measurement, as called for in the definition of plate resistance. The plate voltage and plate current were measured without any shunting resistor in the circuit. In our lab, the plate voltage was 76 volts, and the plate current was 0.7 ma. Then the shunting resistor was added to produce a small change in plate voltage. The plate voltage increased to 87 volts, and the plate current increased to 0.9 ma. A change of 11 volts in the plate voltage produced a change of 0.2 ma in the plate current, corresponding to a plate resistance of 55,000 ohms.

This value of plate resistance is only correct at an average plate current of 0.8 ma. The plate resistance varies with plate current, as shown in Fig. 22-8. An increase of plate current causes a decrease in the plate resistance.